Internet Peer-to-Peer Communication Based Distribution Loop Control System

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(ABSTRACT)

This thesis describes the application of microprocessor based relays with internet communication capabilities in distribution protection systems. The traditional distribution protection system (recloser, sectionalizers) was configured to automatically isolate faulted circuits as well as to reenergize unfaulted loads after a certain number of reclosing operations. Internet Peer-to-Peer communication enables distribution relays to communicate with others connected to the communication network without having a master device. According to the results, the addition of peer-to-peer communication to a traditional distribution protection system significantly enhances its general performance eliminating undesired losses of unfaulted load. Additionally, it reduces outage duration as well as thermal and mechanical stress due to successive re-energizations under faults condition.

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Chapter 1: Introduction

This work describes the application of microprocessor based relays with internet communication capabilities in distribution protection systems. The traditional distribution protection system (recloser, sectionalizers) was configured to automatically isolate faulted circuits as well as to re-energize unfaulted loads after a certain number of reclosing operations. According to the results obtained form this work, adding peer-to-peer communication to a traditional distribution protection system significantly enhances its general performance reducing outage times as well as thermal and mechanical stress due to successive re-energizations under faults condition.

In this particular application, a peer-to-peer communication system enables distribution relays to share information with others connected to the TCP/IP communication network without having a master device. Every relay is able to ask from, and send to, the network un-requested information. Thus, any relay can master the re-configuration of the distribution system itself after a contingency occurs. The system can be programmed to isolate every possible fault after a certain number of reclosing operations as well as to re-energize unfaulted loads. As a result, the traditional protection system is transformed into an adaptive protection system able to reconfigure itself to successfully face contingency conditions.

This thesis has been broken down in eight chapters. Chapters two, three and four go through basic concepts about distribution systems, protection of distribution systems and peer-to-peer communication. Chapter five details the implementation of the Internet Peer-to-Peer communication based distribution loop control system. Chapter six summarizes and analyzes results. Finally, chapters seven and eight present conclusions and future work.

Chapter 2: Distribution Systems

The electric utility system is usually divided into three segments: generation, transmission, and distribution. A fourth segment, sometimes considered, is subtransmission, which can be considered a subset of transmission since the voltage level overlaps and the operating protection practices are quite similar. Figure 2.1, shown below, illustrates some of the major components of these segments.

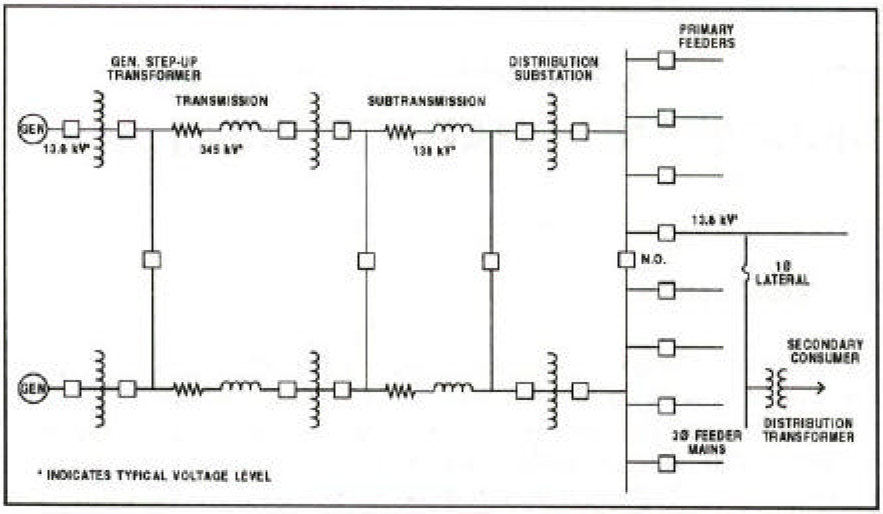


Figure 2.1. Typical Electric Power System.

The distribution system, our main area of interest, is commonly broken down into the following three components:

1.- Distribution substation
2.- Distribution primary
3.- Secondary consumer

Even on this greatly simplified one-line diagram, it can be seen that the distribution system consists of much wider variety of voltages levels, components, loads and interconnections than does the generation or transmission system.

2.1. Distribution Substation

The distribution system is fed through a distribution substation. A typical distribution substation is shown in Figure 2.2. These substations have an almost infinite number or arrangement and voltages. They are customized according to the load that they service. The load types can be: industrial, commercial, residential, and public. The preferred high side voltage level is 115 or 138 kV. The average distribution substation has two power transformers rated 35 MVA with and impedance of approximately 10 percent. The low voltage bus is usually split to avoid parallel operation of the power transformers and reduce circulating and short circuit currents. Every feeder is connected to any of the substation low voltage buses by breakers or reclosers. Short circuits levels at the low voltage bus are usually kept at 12,000 amperes or less. However, there are systems where much higher levels are found. [1]

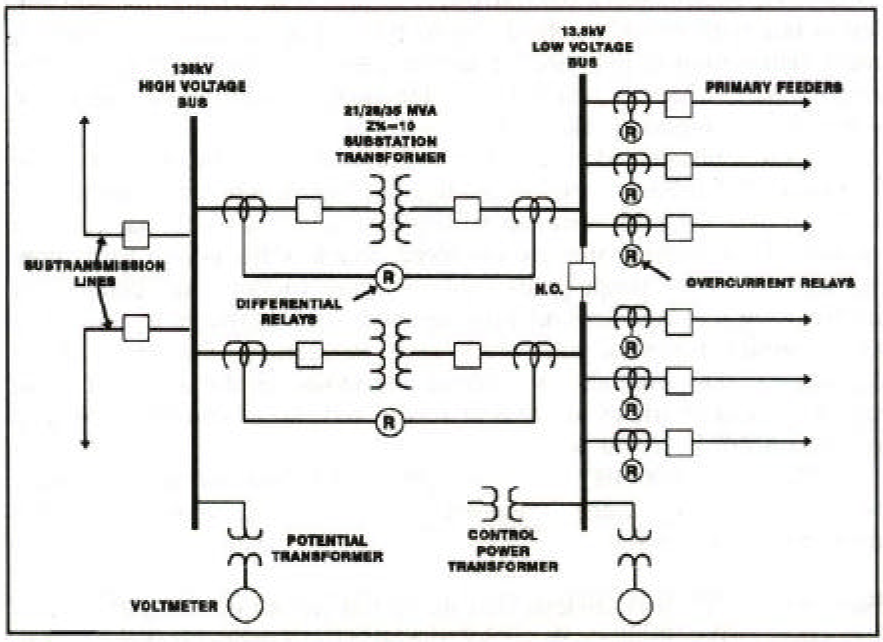


Figure 2.2. Distribution Substation

2.2. Distribution feeders

The power distribution feeder can be either overhead or underground. Overhead power distribution feeders are the most popular among utilities in U.S. due to their low initial investment and their high capacity of transporting energy. Underground distribution systems are used when certain requirements of safety or reliability shall be met. Both technologies are currently used by utilities in the United States. This section discusses some of the most widely used topologies by utilities in the United States for both overhead and underground power distribution systems.

2.2.1. Overhead distribution feeders

Figure 2.3 shows a primary overhead distribution system with various equipments such as fuses, distribution transformer, reclosers, switches, capacitors and arrester. Most overhead distribution feeders are 3-phase and 4-wires. The fourth wire is the neutral wire connected to the pole, usually below the phase wires and grounded. A three phase distribution feeder can be fairly short, on the order of a mile or two, or it can be as long as 30 miles. Voltage levels can be as high as 34.5 kV, with the most common voltage in the 15 kV class. The most common overhead feeder arrangements currently used by U.S. utilities are described as follows:

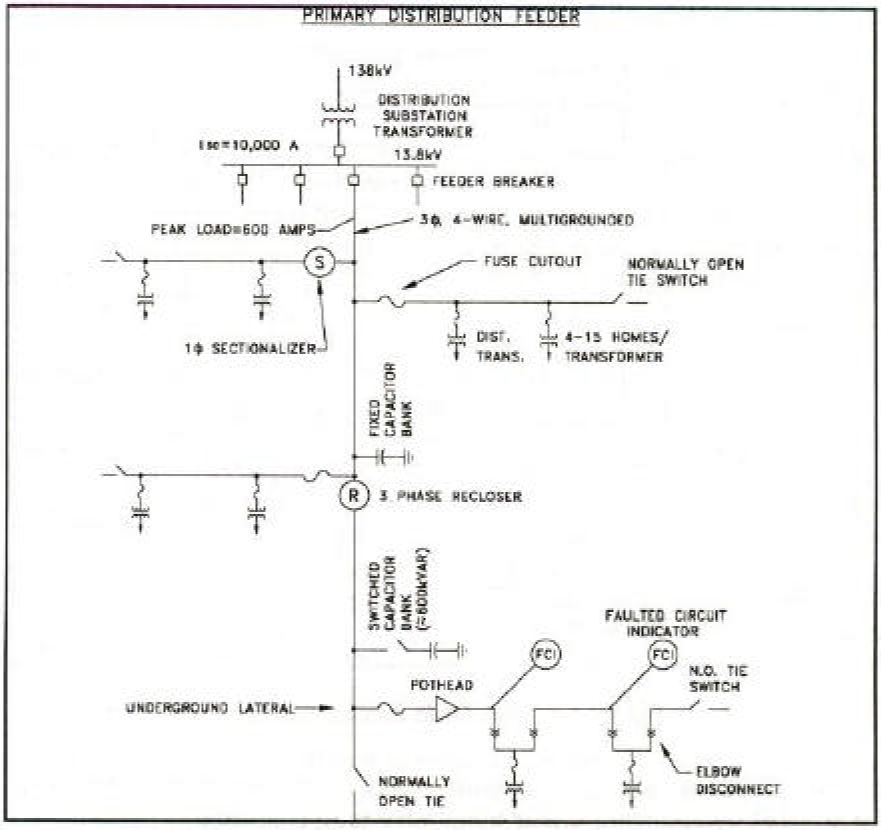


Figure 2.3 Overhead Distribution System

2.2.1.1. Radial system

A typical radial system is shown in Figure 2.4. The flexibility of radial system is very low due to the lack of alternative power sources with only one power breaker connecting the radial system to the distribution substation. Radial systems are the most prone to interruption of service. The most possible outages are related to damage in transformers and faults in feeder. Either of these events involves long interruptions due to the difficulties in locating and fixing the fault. In average, the service restoration takes anything between 10 to 12 hours for U.S utilities [1]. The reliability of radial systems can be improved by introducing recloser and switching devices that automatically detect and isolate momentary fault as well as automatically reestablish service to non-faulted sections of the feeder. The performance of the radial system will be satisfactory only if the interruption frequency is very low and if there are ways to operate the system without planned outages.

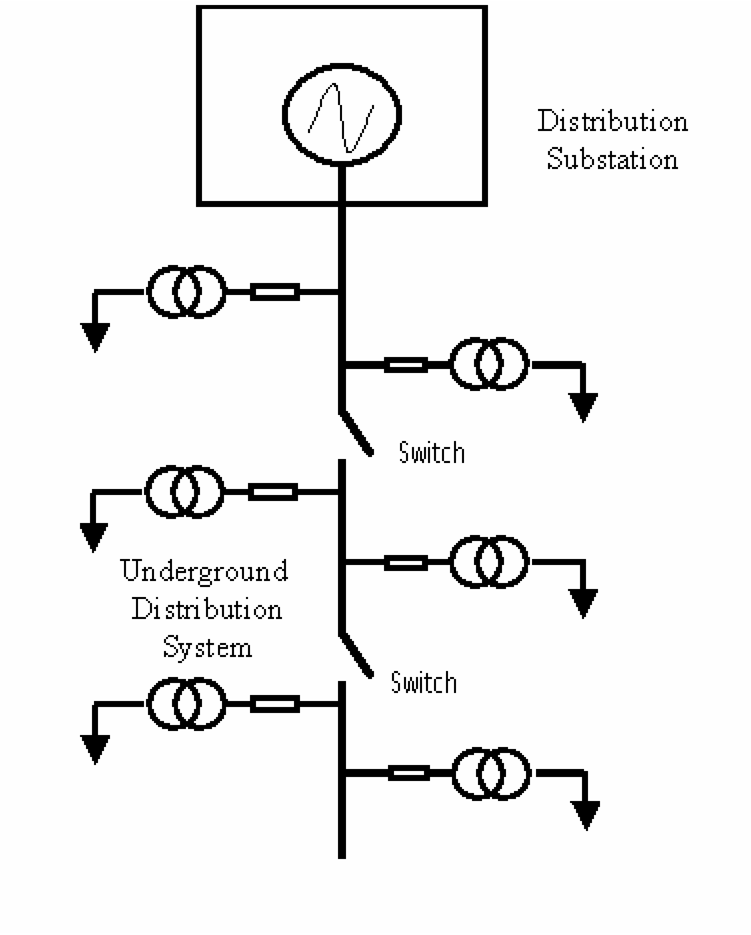


Figure 2.4. Overhead Radial System.

2.2.1.2. Primary loop

The primary loop arrangement significantly improves the flexibility and reliability of the power distribution system by providing a two-way feed at each transformer. It allows isolating any section of the feeder without interrupting the service to the remaining sections. Thus, the average outage time is reduced to the time required to locate the fault and do the necessary switching to restore service. This procedure can be performed either manually or automatically. The general cost for a primary loop arrangement is higher than it is for radial system because all the sections of the primary loop must have capacity to carry the full load of the feeder. Additionally, primary loop requires additional switching devices which increase initial investment. Figure 2.5 shows a typical Primary loop control arrangement.[1]

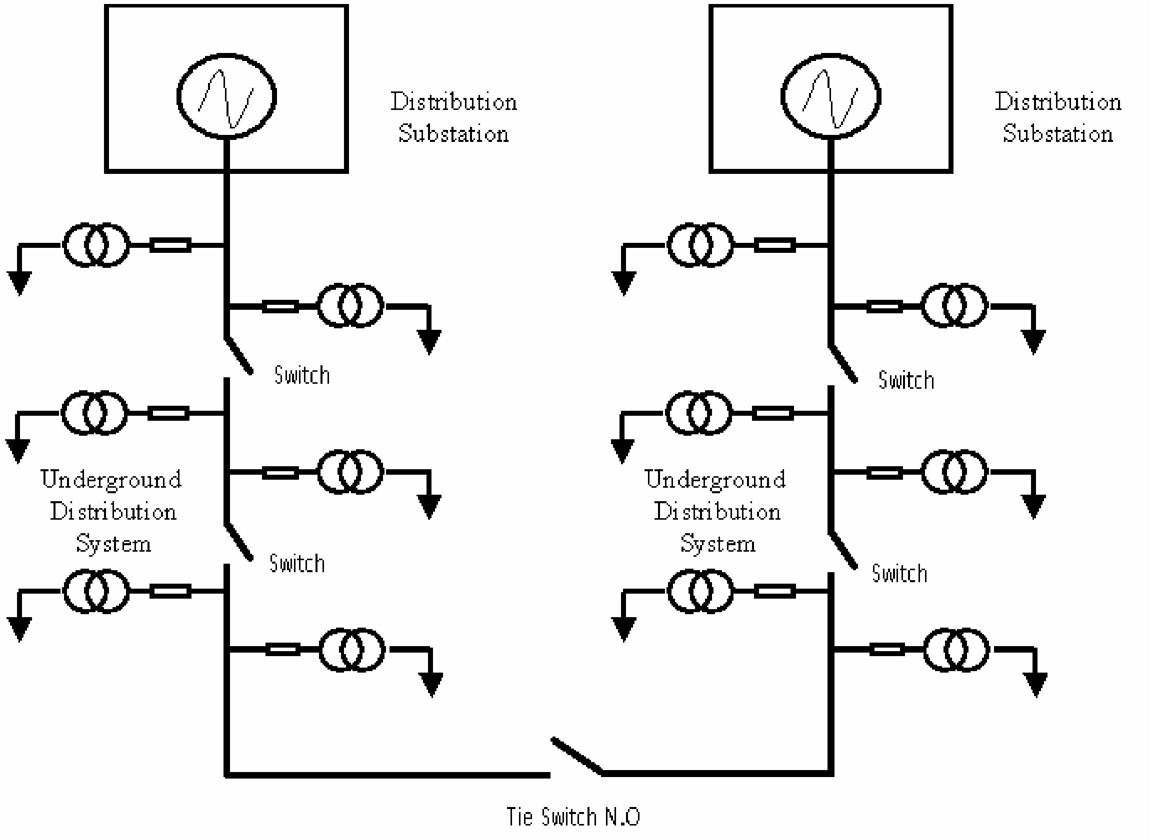


Figure 2.5. Overhead Primary Loop

2.2.2. Underground

While most of the 3-phase Distribution Systems are overhead, most of the new constructions, particularly lateral constructions, are being put underground. Underground systems have the advantage of immunity from certain causes of temporary fault conditions such as wind, direct lighting strikes, animals, etc. Permanent fault on the other hand, are much more difficult to locate and repair and have been the subject of concern in recent years. [1]

2.2.2.1. Radial Systems

Most utility underground and overhead radial systems are similar (i.e, they deliver power in one direction to load at the end of the feeder), however, there are a few differences that exist between the designs. One of these differences can be found in the use of switching devices. Underground switching devices are costly; therefore, the underground feeder designer reserves their use to very particular situations such as load transfer functions. On the other hand, underground radial systems resemble overhead systems in that a main line feeder exists, supplying power to lateral loads protected by fuses. Other systems do not contain a main feeder line; instead they consist of several main branches with various layers of loads and coordinated fuses. Figure 2.6 and Figure 2.7 display the two systems described in this paragraph.

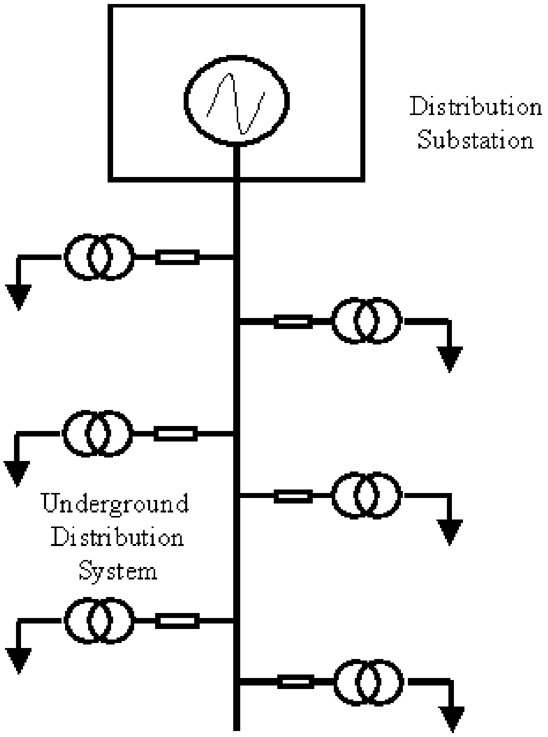


Figure 2.6. Underground radial system with Main Feeder Line

For both systems displayed in the above mentioned figures, the substation circuit breaker is responsible for clearing any faults on the underground cables, especially for systems with a main feeder line, while fuses supply protection for transformer faults. For the branched system shown in Figure 2.7, the layered fuses supply some protection for the cables, as well as protection for the transformers.

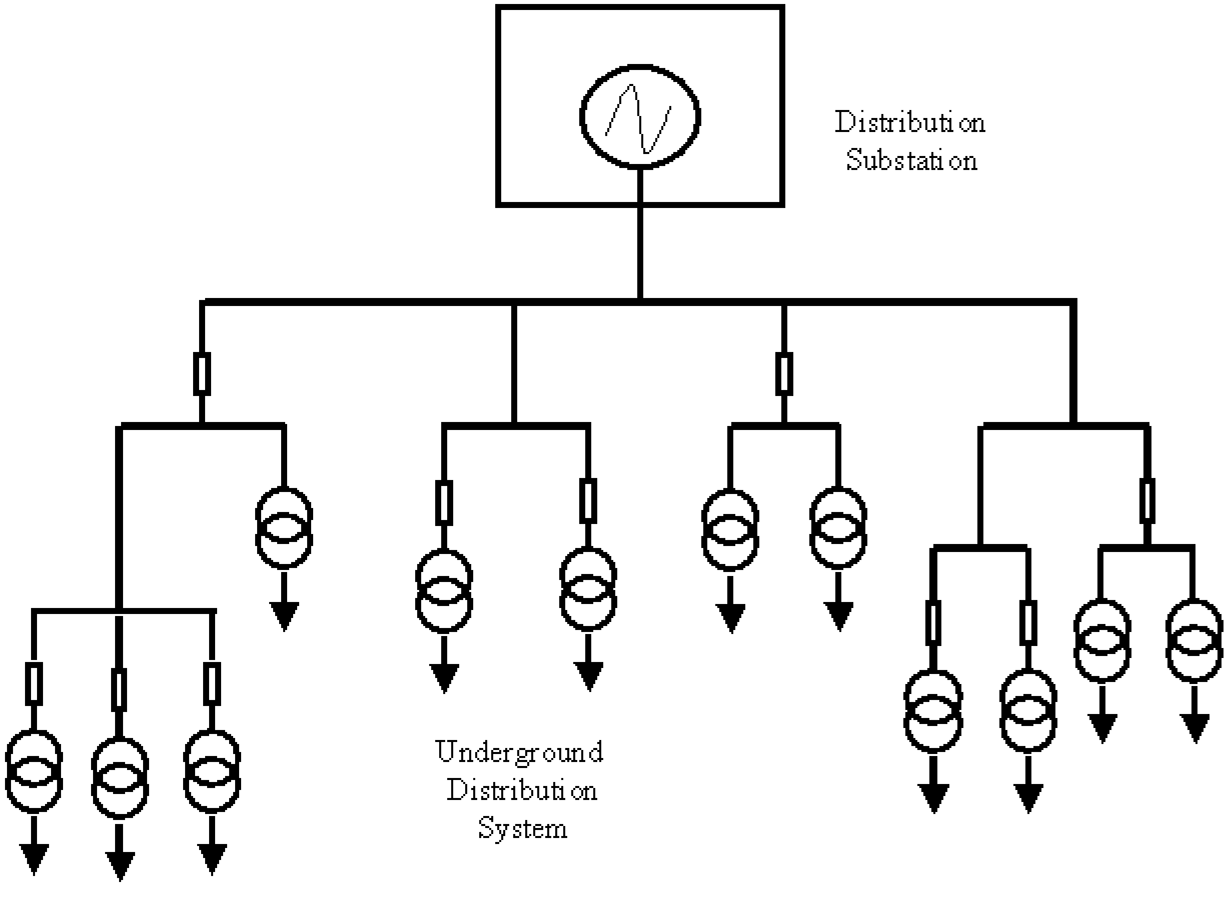


Figure 2.7. Underground Radial System with Several Branches

2.2.2.2. Looped system

The configuration of looped systems varies significantly compared with that of radial systems. Power is also delivered in a radial fashion in a looped system. However, the possibility for system reconfiguration exists in a looped system, where it does not in a radial system. Looped systems are typically three phase system with two sets of switches, a fuse and a distribution transformer located at each load point in the loop. A looped system is shown in Figure 2.8. Padmount switchgear is typically used in a loop configuration by utilities today.

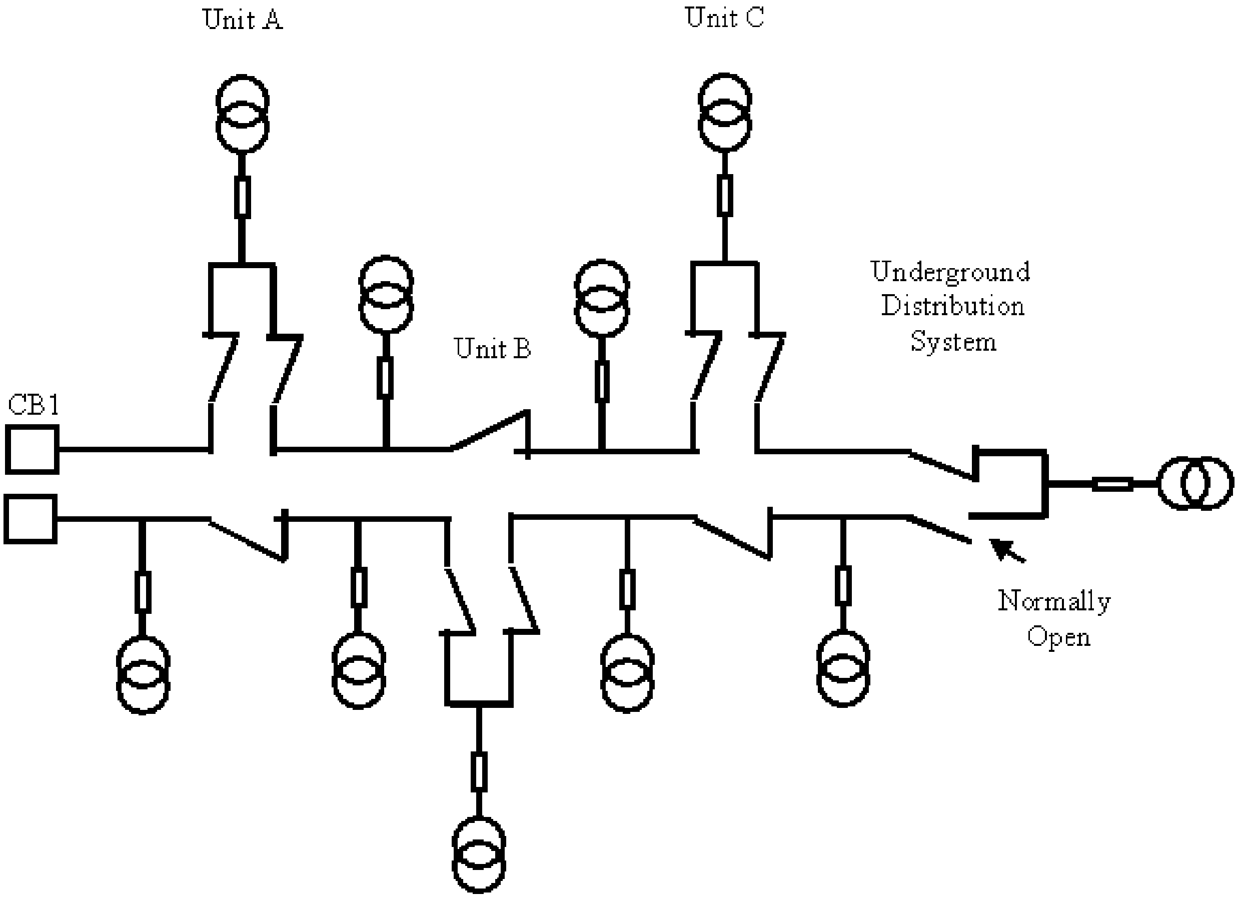


Figure 2.8. Looped Underground Distribution System

Chapter 3: Distribution Overcurrent Protection Devices

This section discuses some of the most popular overcurrent protection schemes used in distribution systems. As was explained in the previous section, distribution systems are mostly radial. This characteristic makes the distribution overcurrent protection considerably different from any other part of the electric system. Distribution Systems are made up of breakers, circuit switchers, load break disconnect, fuses, overcurrent relays, recloser and sectionalizer . The basic concept behind overcurret protection of distribution systems is the premise that the fault current decreases as distance from the substation increases. This premise is especially valid for radial systems where the fault current is solely limited by the impedance between the fault spot and the substation. This decreasing pattern allows current and time coordinated operation of protection devices along the distribution system.

3.1. Distribution Overcurrent Protection Devices

3.1.1. Fuses

Fuses are the most basic and cost effective type of overcurrent device presently being used by the utility industry. They are also some of the most reliable devices providing their function for over 20 years with essentially no maintenance.[1]

A fuse is defined by the National Electrical Manufacturers Association (NEMA) as "a device which protect a circuit by fusing open its current responsive element when an overcurrent or short-circuit current passes through it." The fusible element of a fuse opens in a time that varies inversely with the magnitude of the current that flows through the fuse. The time-current characteristic depends on the rating and the type of fuse. Figure 3.1 shows a typical fuse time-current characteristic. [2]

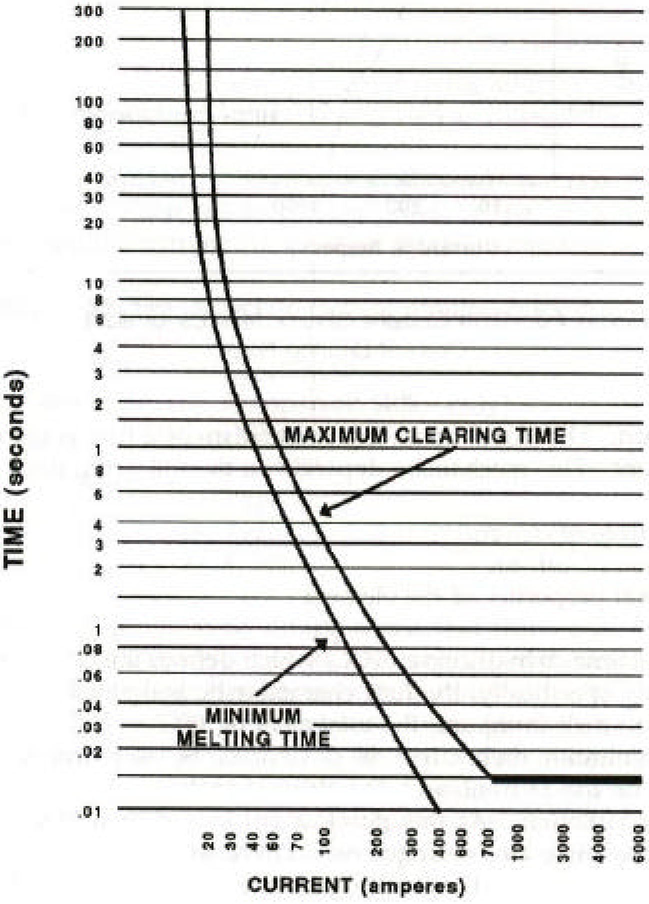


Figure 3.1. Fuse time-current Characteristic.

3.1.2. Relays

Protective relays are devices that are used as sensing element to detect abnormal conditions in the distribution system. Correctly selected and set sensing devices can provide much greater accuracy than direct acting devices such as fuses. They are used in all medium-voltage and high-voltage circuit breaker as overcurrent detecting element. Overcurrent relays can be classified according to their operating time-current characteristic into instantaneous or temporized. Instantaneous overcurrent relays operate immediately after the overcurrent is detected. In other words, no intentional delay is introduced in the operation of instantaneous overcurrent relays. Temporized overcurrent relays operate after the fault is detected and the intentional delay time is up. Commonly, temporized overcurrent relays operated in a time that varies inversely with the magnitude of the current that flows through the relay. It is called as inverse time characteristic.

3.1.3. Recloser

An automatic circuit recloser is a self contained device which can sense and interrupt fault currents as well as re-close automatically in an attempt to re-energize a line. The operation of the recloser is very similar to that of a feeder breaker with a recloser relay. The main difference between the two devices is that the recloser has less interrupting capacity and lower cost. Recloser applications are limitated to overhead distribution systems. Underground recloser applications are not allowed due to the stress cables are put through during every reclosing operation. Furthermore, the likelihood of temporary fault occurrence for underground distribution system is very low, because underground feeders are not directly exposed to the environment.

3.1.3.1. Old Fashion Recloser

Old fashion recloser operation utilizes two inverse time curves. Figure 3.2 shows a typical recloser's time-current characteristic. The first curve referred as the instantaneous or A curve, is similar to an instantaneous relay and is used primarily to save lateral fuses under temporary fault conditions. The second curve referred as "time delay" or "B" (also C,D,E) is used to delay recloser tripping and allow the fuses to blow under permanent fault conditions. The recloser time delay curves (B,C,D,E) are fixed. This is in contrast to an inverse-relay curve which has an infinitely adjustable time dial. On the other hand, a recloser may have more than one instantaneous operation in an attempt to dissipate a temporary fault condition whereas the feeder relay can normally have only one. The most typical reclosing sequence for a recloser is two fast operations followed by two slow ones (2A, 2B).

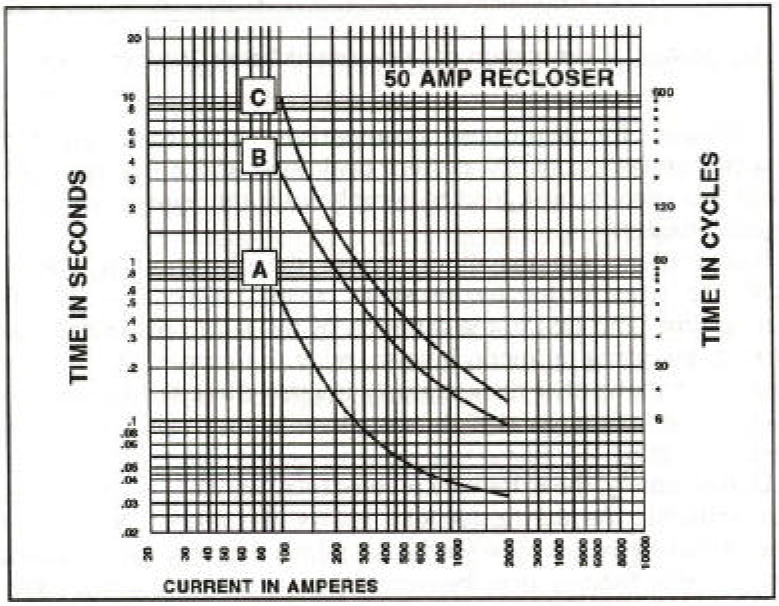


Figure 3.2. Recloser time-current characteristic

Major classifying features in automatic circuit reclosers are:

- Single-or three-phase.
- Control: Hydraulic or electronic.
- Interrupters: Oil or Vacuum.

3.1.3.1.1. Single phase or three-phase

Single-phase reclosers are used to protect single-phase lines such as branches or taps of a three-phase. Also, they can be used to isolate single-phase loads. Three-phase reclosers are used where lockout of all the three phases is required for any permanent fault. They are also used to prevent single-phasing of the three-phase loads such as three-phase motors.

3.1.3.1.2. Control: Hydraulic or Electronic Fuses

The full control of the recloser is provided by either a hydraulic control system or an electronic control unit. A hydraulic control system is embedded inside the recloser device and is used on single-phase reclosers and low rating three-phase units. With this type of control, the overcurrent is sensed by a trip coil that is connected in series with the line. When the overcurrent flows through the coil, a plunger is drawn into the coil to trip open the recloser contacts. Minimum trip current for this type of recloser is two times the rating of the recloser.

The electronic control is located in a separate cabinet and is more flexible and easier to adjust permitting a wider range of possible time and trip current settings. The fault current is sensed by special CT's inside the recloser.

3.1.3.1.3. Interrupters - oil, Vacuum, and SF_6

The recloser's interrupting technology is similar to the one used on circuit breakers. Recloser's interrupting means can be oil, vacuum and SF_6. The major different between circuit breakers and reclosers is the greater continuous current and short circuit interruption rating of the formers. Reclosers are usually imitated to current ratings up to 600 A and short circuit interruption ranting up to 16,000 A.

3.1.3.2. State of the Art Recloser Devices

State of the art reclosers improve flexibility, reliability and maintenance requirements with respect to its predecessors. New vacuum interrupting and encapsulating technologies eliminate the need for gas or oil in the construction of recloser devices. State of the art recloser devices are made up of vacuum interrupters units encapsulated in polyurethane materials. They produce a clean interruption with minimum exposition to the environment. As a result current recloser units are almost maintenance free; some units are capable of thousand of operations without scheduling maintenance. Figure 3.3 shows one of the reclosers that are currently available for distribution systems. It is equipped with a magnetic actuator which reduces the number of parts and increases reliability. This maker assures that the unit has no schedule maintenance beyond changing batteries approximately every five years.

Figure 3.3. State of the art recloser

Besides the above mentioned improvement in the interrupting hardware, the control units have also been upgraded according to the most recent microprocessor advances. State of the art recloser control units can provide, in addition to its traditional recloser functions, SCADA friendly interface for remote communication with remote SCADA systems via several communication protocols. This built-in communication allows remote operation of the recloser. Reclose control units can also include many other functions such as: Fault location, under and over voltage control and alarm, under and over frequency voltage alarm, system restoration, power quality, billing, loop control, etc. Thus, reclosers are no longer a stand alone units. They can be interconnected into a sharing information system capable of improving the general performance of the distribution system.

3.1.4. Sectionalizers

A sectionalizer is a protective device, used in conjunction with recloser which isolates faulted sections of the line. The sectionalizer does not interrupt fault current. Instead, it counts the number of operations of the reclosing devices and opens while the recloser is open. After the sectionalizer opens, clearing the faulted section, the backup device recloses to return power to the unfaulted sections of the line. If the fault is temporary, the sectionalizer will reset itself after a prescribed period of time. A sectionalizer provides several advantages over fuse cutouts by adding flexibility, safety and convenience.

In the same fashion than reclosers, state of the art sectioanlizers are mostly made up of encapsulated vacuum interrupters. Furthermore, sectionalizer control units are also capable to support communication, supervision and control function as well as its own sectionalizer control functions.

3.2. Recloser and sectionalizers Protection Scheme Operation

This section is devoted to explain the operating principles of the combination recloser and sectionalizer. As was mentioned in section 3.1.3, reclosers can sense and interrupt fault current as well as automatically re-close in an attempt to re-energize a faulted line. Experience has shown that a high percentage of faults in distribution system are self-extinguishing. It means that the overcurrent produced by the fault goes out by itself. This particular characteristic is what makes reclosers useful in protection of distribution systems. If during any of the faulted distribution feeder re-closing operations the fault gets extinguished, the electric service will be permanently reestablished in the next operation of reclosing. If the fault is still present during the last reclosing operation the system concludes that the fault is permanent and the recloser is locked out. The reclosing sequence of a feeder is usually one fast trip followed by several time delayed trips. The time between the reclosures (recloser is open) is called the dead time. A typical sequence of dead times is 0,15 or 30 seconds. The instantaneous tripping takes about 6 cycles, which includes 1 cycle for the instantaneous relay and 5 cycles for the recloser.

Although the above discussed scheme has the advantage of reducing outages causeed by temporary faults, it has the important disadvantage of the high stress put on the system during each re-closing operation. If the recloser is set to three re-closing operation and the fault is permanent (non auto-extinguishing) the system will have to carry the fault current four times before the fault is permanent cleared and all in a very short period of time. This situation puts high mechanical and thermal stress on the feeder and the distribution substation. Furthermore, the voltage drop caused by the fault might affect the quality of service to other customer connected to the same distribution substation. Another disadvantage of reclososer based protection schemes is related to flexibility of the system. The only way to permanently clear faults is shutting down the whole feeder since there is not way to sectionalize the feeder and isolate the faulted section.

The recloser protection scheme can be improved by adding sectionalizer devices into the distribution feeder. Sectionalizers were introduced in section 3.1.4. They are devices capable to isolate faults during the recloser's dead time and after a certain number of reclosing operations. As it can be inferred from the above introduction, sectionalizer are intended to work in conjunction with reclosers. The operating principle behind the recloser-sectionalizer scheme will be detailed using the distribution feeder model shown in Figure 3.4.

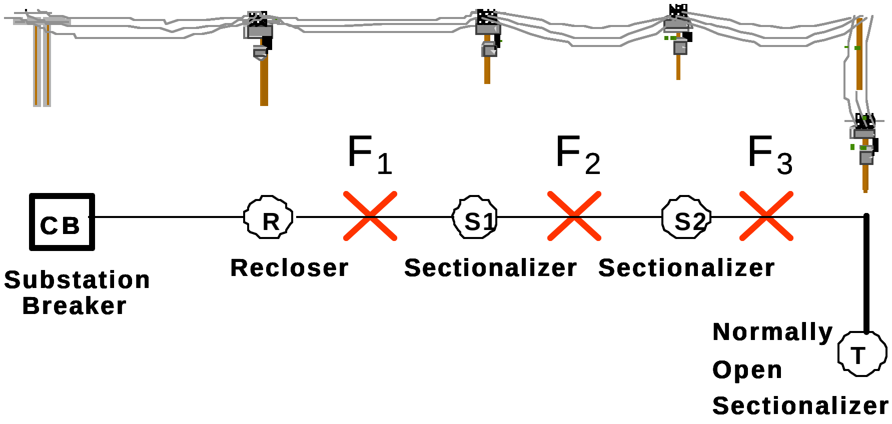


Figure 3.4. Distribution Feeder Protection scheme

The distribution feeder model is equipped with one recloser (R) and two sectionalizers (S1 and S2). The recloser is set to allow three reclosing operation with the dead times shown in Figure 3.5. Additionally, sectionalizers S2 and S1 are set to open after the first and second reclosing operation respectively.

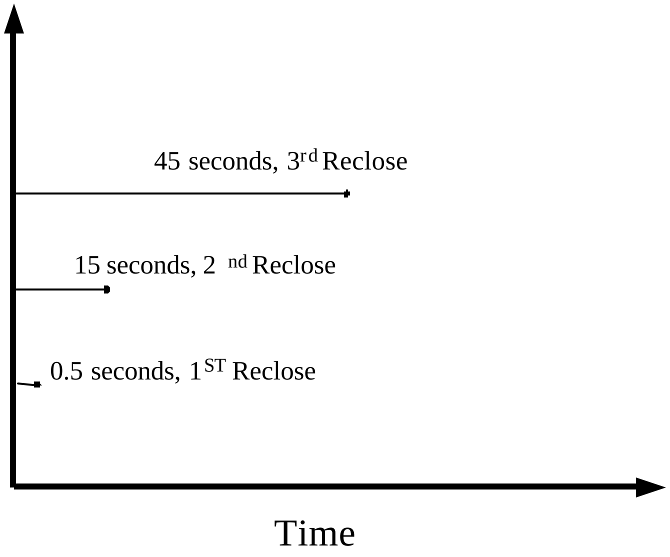


Figure 3.5: Sequence of operations for the Recloser

Table 3.1 shows the expected final condition of the system when a fault occurs at F1, F2 or F3.

Table 3.1. Recloser-Sectionalizer Protection Scheme Operation

Fault location	Reclosing operations	Recloser' status	Sectionalizer S1's status	Sectionalizer S2' status	Recovering time (s)	% Load recovering
F1	3	Open	Close	Close	N.A.	0 %
F2	2	Close	Open	Close	60	33 %
F3	1	Close	Close	Open	15	66 %

For a fault happening at F3 the recloser initially opens clearing the fault. 500 milliseconds later the recloser performs the first reclosing operation. If the fault is still there, the recloser will open again. At this stage sectionalizer S2 recognizes the first reclosing operation and opens isolating the faulted section. 15 seconds later the recloser will successfully perform its second reclosing operation re-establishing service to loads located between the transformer and the sectionalizer S2.

In case that the fault happens at F2, sectionalizer S2 does not see any fault current; therefore it does not count reclosing operations. Sectionalizer S1, which do see the fault current, will open after the second reclosing operation (15 seconds after the first reclosing operation) isolating the fault. 45 seconds later the recloser will successfully perform its third reclosing operation recovering the load connected between the transformer and the sectionalizer S1. It is important to notice that although the feeder section located down stream of S2 is not faulted, it remains out of services after the third reclosing operation.

Finally, for faults at F1 neither sectioanlizer S1 nor sectioanlizer S2 senses the fault current; therefore, they are not intended to operate under this situation. Thus, in an event of permanent fault at F1 the recloser will perform three unsuccessful reclosing operations and end up open and locked out. The distribution feeder is totally shut down. Although loads located down stream of S1 are not faulted they remain out of service after the third reclosing operation.

In brief the tradition recloser-sectionalizer distribution scheme increase the performance of the distribution system by allowing to clear permanent fault without shutting down the whole feeder. The major negative effect of this approach is the increment on thermal and mechanical stress put on the distribution feeder due to several application of the fault current in a relatively short period of time.

Chapter 4: Peer to Peer Communication

Peer-to-peer computing is the sharing of computer resources and services by direct exchange between systems. These resources and services include the exchange of information, processing cycles, cache storage, and disk storage for files. Peer-to-peer computing takes advantage of existing desktop computing power and networking connectivity, allowing economical clients to leverage their collective power to benefit the entire enterprise.

In a peer-to-peer architecture, computers that have traditionally been used solely as clients communicate directly among themselves and can act as both clients and server, assuming whatever role is most efficient for the network. This reduces the load on servers and allows them to perform specialized services such as mail-list generation, billing, etc. more effectively. At the same time, peer-to-peer computing can reduce the need for Information Technology organizations to grow parts of its infrastructure in order to support certain services, such as backup storage.

In the business field, peer-to-peer is about more than just the universal file-sharing model popularized by Napster. Business applications for peer-to-peer computing fall into a handful of scenarios.

1. Collaboration. Peer-to-peer computing empowers individuals and teams to create and administer real-time and off-line collaboration areas in a variety of ways, whether administered, unadministered, across the Internet, or behind the firewall. Peer-to-peer collaboration tools also mean that teams have access to the freshest data.
Collaboration increases productivity by decreasing the time for multiple reviews by project participants and allows teams in different geographic areas to work together. As with file sharing, it can decrease network traffic by eliminating e-mail and decrease server storage needs by storing the project locally.

2. Edge services. Peer-to-peer computing can help businesses deliver services and capabilities more efficiently across diverse geographic boundaries. In essence, edge services move data closer to the point at which it is actually used acting as a network caching mechanism. For example, a company with sites in multiple continents needs to provide the same standard training across multiple continents using the Web. Instead of streaming the database for the training session on one central server located at the main site, the company can store the video on local clients, which act essentially as local database servers. This speeds up the session because the streaming happens over the local LAN instead of the WAN. It also utilizes existing storage space, thereby saving money by eliminating the need for local storage on servers.

3. Distributed computing and resources. Peer-to-peer computing can help businesses with large-scale computer processing needs. Using a network of computers, peer-to-peer technology can use idle CPU MIPS and disk space, allowing businesses to distribute large computational jobs across multiple computers. In addition, results can be shared directly between participating peers.

The combined power of previously untapped computational resources can easily surpass the normal available power of an enterprise system without distributed computing. The results are faster completion times and lower cost because the technology takes advantage of power available on client systems.

4. Intelligent agents. Peer to peer computing also allows computing networks to dynamically work together using intelligent agents. Agents reside on peer computers and communicate various kinds of information back and forth. Agents may also initiate tasks on behalf of other peer systems. For instance, Intelligent agents can be used to prioritize tasks on a network, change traffic flow, search for files locally or determine anomalous behavior and stop it before it effects the network, such as a virus.

4.1 *Peer-to-Peer communication in automation, protection, and control of power and distribution systems*

Peer to Peer computing applied to power systems has been mostly focused on the implementation of wide area networks structures in the Substation Automation. Wide area networks allow the execution in a substation of protection and control functions that require information coming from a more extensive area than the substation itself. Normally the information needed is coming directly from interconnected substations, but it can also be information coming from an even wider area or connected networks e.g. from different voltage levels. Possible applications of wide area networks range from regional interlocking and synchronization schemes, regional voltages control schemes up to inter-tripping, system restoration and protection schemes.

Over the last years the incorporation of LAN and WAN technologies in the Automation and control of electrical power networks have become more and more common. Both inside and outside the substation environment, devices and communication protocol have been or are being adapted to the use of local and wide area networks. The use of computer networks like Ethernet for communication between intelligent electronic devices (IEDs) offers speed, transfer capacity and versatility. Thus, the implementation of wide area functions is now feasible. According to IEEE Std C37.1-1994, Intelligent Electronic Devices are defined as "any device incorporating one or more processor with the capability to receive or send data/control from or to an external source (e.g. electronic multifunction meter, digital relays, controllers). Within this concept, all IEDs should be able to communicate to one and other in a common software environment involving standardize object model for each IEDs (peer to peer communication).

Classical power network control systems are mostly based on SCADA structure. Thus, data collecting devices (RTUs) communicate with a hierarchically higher-level device in a master-slave communication structure. The current development on the communication protocol level such as IEC 60870-5 and IEC 60870-6 enable date collecting device (RTUs or IEDs) subsystem to communicate to any other subsystem connected and addressable on the communication link (Peer to Peer). Although the IEC 60870-5-104 is a network oriented communication protocol, the structure it is embedded in is still the classical SCADA/Telecontrol structure.

The feasibility of wide-area applications will depend heavily on the realization of standardize communication and standardize data modeling of IEDs. The UCA^{TM} 2.0 initiative in the USA is an attempt to meet these requirements. IEC 61850 takes this effort one step further; incorporating the UCATM 2.0 works, and extending it towards the process level. The harmonization of data models between UCA^{TM} 2.0 and IEC 61850 will eventually be an important step towards a worldwide-accepted standard.

Several applications for Peer-to-peer communication to power system are outlined in the "IEEE-PSRC working group H5 – Application of Peer-to-Peer Communication for Protective Relaying" document, dated December 2001. In section 6.1 of the cited document, a fault insulation application using Peer-to-Peer communication is proposed. This particular approach states "Fault isolation can be locally implemented in a feeder Switch or Recloser by monitoring the operation of the operation of the station feeder breaker and the local fault detection.

Chapter 5: Internet Peer to Peer communication based Recloser and Sectionalizer Protection Scheme.

As was presented in the previous chapter, the traditional recloser-sectionalizer scheme is intended to work without any kind of communication between the protective devices that make up the distribution system. The communication capability with which state of the art microprocessor based reclosers and sectionalizers are currently featured opens a whole new world of potential improvements for distribution systems and for power systems in general. This section addresses one particular application in which a peer-to-peer communication system enables recloser and sectionalizers to share information with each others without having a master device. Every relay is able to ask from, and send to, the network un-requested information. This communication feature enables the system to locate and isolate faults without waiting for the recloser's operations. Furthermore, and even more important, any distribution protection device can master the re-configuration of the distribution system itself after a contingency occurs. Thus, the system can be programmed to isolate every possible fault after a certain number of reclosing operations as well as to re-energize unfaulted loads. As a result, the traditional protection system is transformed into an adaptive protection system able to reconfigure itself to successfully face contingency conditions.

5.1 Distribution system Model Configuration

The internet peer-to-peer communication based recloser-sectionalizer protection scheme was developed and implemented for a typical overhead primary looped system. The system model is shown in Figure 5.1. Every branch of the model is furnished with one recloser, two sectionalizes and one tie breaker which is shared for both branches. The operating condition of the tie breaker is normally open. It closes only upon the event of loss of power in any of the branches to supply backup power from the other branch. The recloser-sectionalizer scheme is assumed to work in a fashion similar to the one described in section 3.2. Microprocessor based type units were used as recloser and sectionalizer control units.

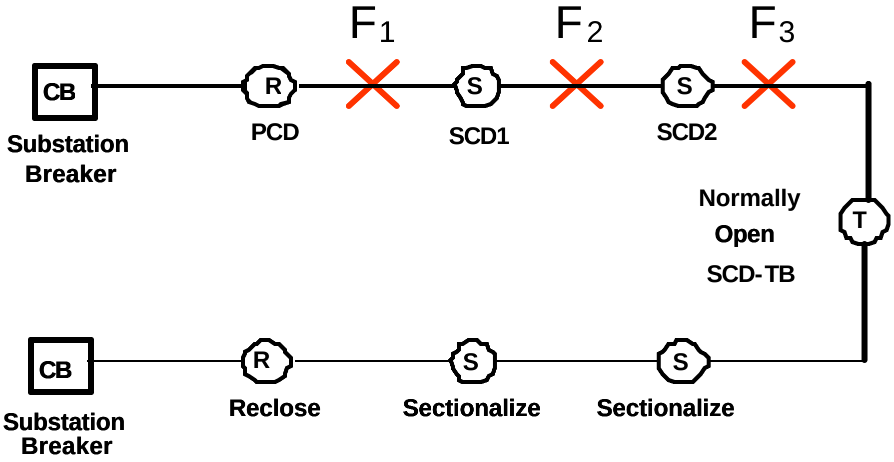


Figure 5.1 Power Distribution System Model

A Distribution Feeder Analog Simulator was used to implement and test the internet peer to peer communication based recloser-sectionalizer scheme. The model of the distribution feeder was built in a 19 inch panel which is shown in appendix A. The main components of the panel are: a source section, four line sections, one recloser section, and three sectionalizer sections.

The source section is composed by a variable three-phase voltage source and a thermo-magnetic circuit breaker. The three-phase voltage source represents the low voltage winding of the substation transformer, and the thermo-magnetic circuit breaker represents the feeder circuit breaker.

The line sections model the distribution feeder lines. Each unit includes: three phase inductors (one per phase), one neutral inductor, one single-pole toggle switch, two three-pole toggle switches, and three resistors. Figure 5.2 shows the arrangement of the elements in the line section. The phase inductors (RL) represent the impedance of the distribution line. A neutral inductor (RN) was added in order to obtain the proper line to neutral fault currents. A three-pole toggle switch (TFF) applies a solid three-phase fault in the particular line section of the distribution feeder. In a similar fashion, a single pole toggle switch (SFF) is used to apply single-phase to ground faults. The resistors (Ω) represent a three phase local load, which is energized by a three-pole toggle switch.

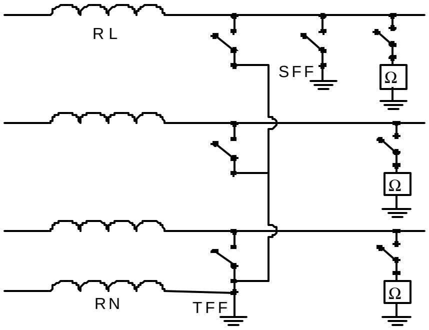


Figure 5.2. Elements arrangement inside the Line Section

The recloser section includes a low voltage contactor which models the recloser, as well as the actual relay which is normally installed in the distribution line pole. The microprocessor based relay controls the low voltage contactor for manual commands as well as for automatic commands related to the contingency state of the feeder. The low voltage contactor in this section has the capability of interrupting short circuit currents. The opening of this device isolates the source and de-energizes the distribution feeder.

The sectionalizer section was modeled similarly to the recloser section. A fundamental difference, however, is the fact that the low voltage contactors which model the sectionalizers do not have the capability of interrupting short circuit currents. These devices are allowed to open only during the period of time the recloser is opened, i.e., when the distribution feeder is de-energized. An microprocessor based relay controls the low voltage contactor for manual commands as well as for automatic commands related to the contingency state of the feeder.

5.2 PCD/SCD2000

The Power Control Device 2000 (PCD2000) is a microprocessor-based control unit providing extensive recloser protection elements designed for distribution automation systems. The units combine monitoring, control, protection, reclosing elements and communication in one package. Power quality, accurate metering, load profiling, and condition monitoring provide crucial system information for managing distribution systems. The PCD 2000's communication capabilities allows user to develop distribution automation applications without the need of remote terminal units (RTU) with DNP 3.0, Modbus RTU or ModbusASCII. The PCD can be remotely operated to reconfigure the distribution systems during contingent situations making the system operation more efficient. In this particular application the communication and data processing capabilities of the PDC2000 are used to develop an internet based loop control application that allows quick location and isolation of faults as well as automatic reconfiguration of the distribution system.

Based on the PCD2000 framework the Switching Control Device (SCD2000) provides full switch control function. In the same fashion than PCD2000 units, SCD units combine monitoring, control, switching and communication in one Package.

5.2.1 PCD/SCD2000's Features

The PCD provide the following features:

1. Protection.
2. Reclosing.
3. Metering.
4. Programmable control.
5. Communications.
6. Power quality.
7. 3 Phase operation.
8. Single Phase operation.

9. Local and remote fault status indication.
10. Records and reports operation and fault data.
11. Remote and local communications.
12. Programmable I/O contacts.
13. Fault Location (3 phase only).
14. DNP 3.0 and MODBUS or ASCII MODBUS RTM protocol communication capabilities.
15. Recloser failure detection and alarm.
16. Weather proof, front-mounted optical port for optical isolation.
17. Digital Metering: voltage, current, kWh, kVarh, power factor, demand watts, VARs and frequency.
18. Oscillography.
19. ANSI and IEC recloser and user programmable curves.
20. Three setting groups.

5.2.2 PCD2000’s Protective Functions

1. Phase time over-current protection (51P).
2. Phase instantaneous over-current protection (50P-1, 50P-2, 50P-3).
3. Ground over-current protection (51N).
4. Ground instantaneous over-current protection (50N-1, 50N-2, 50N-3).
5. Negative sequence over-current protection (46).
6. Phase and ground directional over-current protection (67P, 67N).
7. Three frequency functions: load shedding, restoration, and over frequency (81S, 81R, 81O).
8. ANSI, Cooper and programmable curves.
9. Multishot reclosing: each reclose step allows independent programming of protective functions (79-1, 79-2, 79-3, 79-4, 79-5).
10. Reverse power (32P, 32N).

5.3 TCP/IP communication based

The TCP/IP protocol has been chosen as a Peer-to-Peer Communication Platform. It enables devices to have access to either Internet or a private Intranet. Therefore, communication availability constrictions are curbed by using a widely spread communication protocol. Figure 5.3 shows the architecture of the proposed system. The scheme must be implemented with a fall-back operation procedure for those times when communication is not available. This fall-back operation procedure operates similar to the traditional non-communication recloser-sectionalizer scheme described in section 3.2.

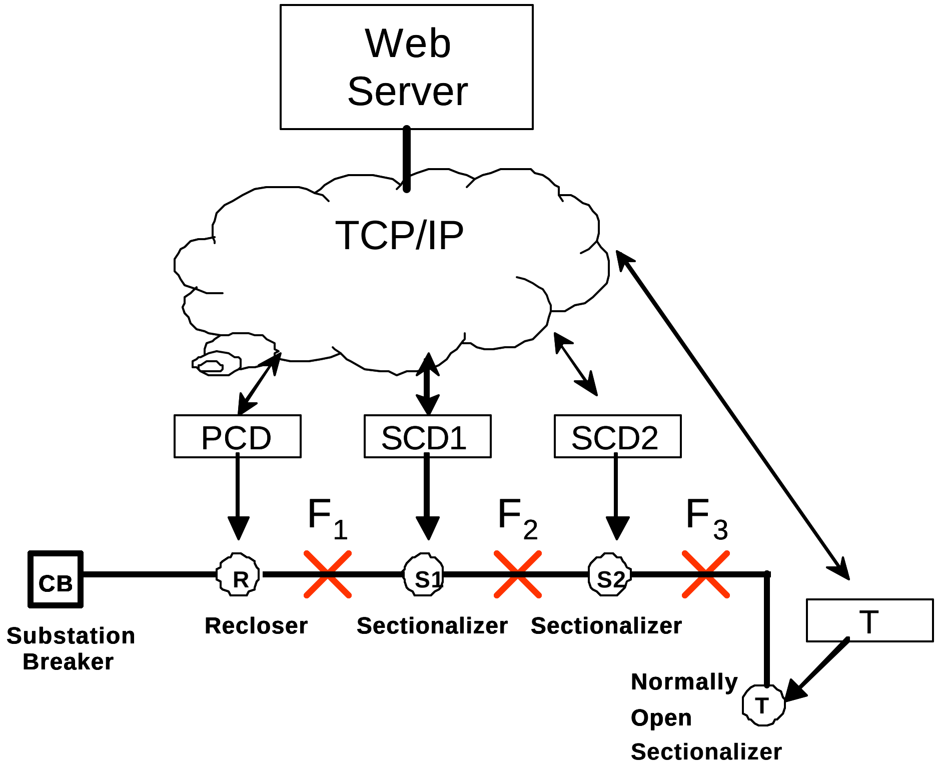


Figure 5.3. Web-Based Communication Loop Control

The access to the TCP/IP protocol was accomplished by using low cost Java Application Control Engines. Every PCD/SCD 2000 unit was tied to a Java based control device through a Modbus serial communication link using RS-232 port. Specifically, Jace-501/502 Java based control devices made by Tridium were used. The Jace-501/502 units manage the serial communication with the PCD/SCD control units as well as the TCP/IP access. The Jace-501/502 also run the fault location, fault isolation and system restoration algorithms.

JACE-501/502 series controllers are lower cost Java Application Control Engines built upon a compact embedded PowerPC™ platform with Flash Memory for backup. They provide integrated control, supervision, and network management solutions for a network of LonWorks™ based application controllers. When connected over an Ethernet network, the JACE-501/502 can communicate to BACnet™ devices or systems and share data between the LonWorks devices and BACnet™ systems. Furthermore JACE-501/502 is capable to configure a Modbus serial communication network with one o more Modbus devices using either RS-232 or RS-485 ports. A complete set of Java™ based control, application, logging, and user interface "objects" are included in a library for the Systems Integrator to create a robust control system for any size building. The JACE-501/502 can also be configured with optional Web User Interface Services. In this configuration, the system's graphical views can be accessed using any standard Web browser such as Netscape Navigator™ or Internet Explorer™.

In larger buildings or multi-building complexes and large-scale control system integrations, the Web Supervisor™ in conjunction with one or more JACE-501/502s manages global control functions, supports data passing over multiple networks, and hosts multiple, simultaneous client workstations connected over the local network, the Internet, or dial-up access.

JACE-501/502’s main features:

- Embedded RISC Microprocessor platform.
- Distributes real-time control functions across an Ethernet LAN.
- Cost effective for any size installation.
- Run applications in a single unit.
- Multiple JACE stations can be used in a large scale system configuration.
- Can be configured with Web User Interface services to support many simultaneous users over Intranet or Internet via standard Web browser.

5.3.1 WorkPlace Pro

WorkPlace Pro is a comprehensive set of engineering tools combined into one, common, easy-to-use engineering environment. WorkPlace Pro simplifies the complexity of working with multiple protocols by consolidating them into one common object model. Everything a user needs to manage and integrate multiple protocols is available in one, powerful engineering toolkit.

WorkPlace Pro allows the implementation of control algorithms using information coming from different sources such as communication ports of the device itself or any other device connected to the network. This extraordinary capability lets Jace-501/502 units get information about the condition of the distribution system from fellow devices connected at different spots of the system. It makes possible for Jace-501/502 to have a broad and real-time view of the distribution system which enables the implementation of fault location, fault insulation, and system restoration functions.

WorkPlace Pro features a pre-assembled common object library. For instance, the Boolean module allows the implementation of decision making algorithms based on certain condition of the system. Another useful tool is the ModBus communication module. It allows reading or writing information from the devices connected to the communication network. Figure 5.4 gives an idea of how the WorkPlace Pro looks like.

WorkPlace Pro main Features:

- Powerful Java-based object model
- Quick application development with a preassembled common object library
- Easy-to-use, powerful programming language for custom applications
- Simple, common linking mechanism allows for transparent data sharing between devices of similar or different protocols
- Graphical engineering environment to create, configure and test control system application logic and user interface screens
- Tree diagram representation of database structure

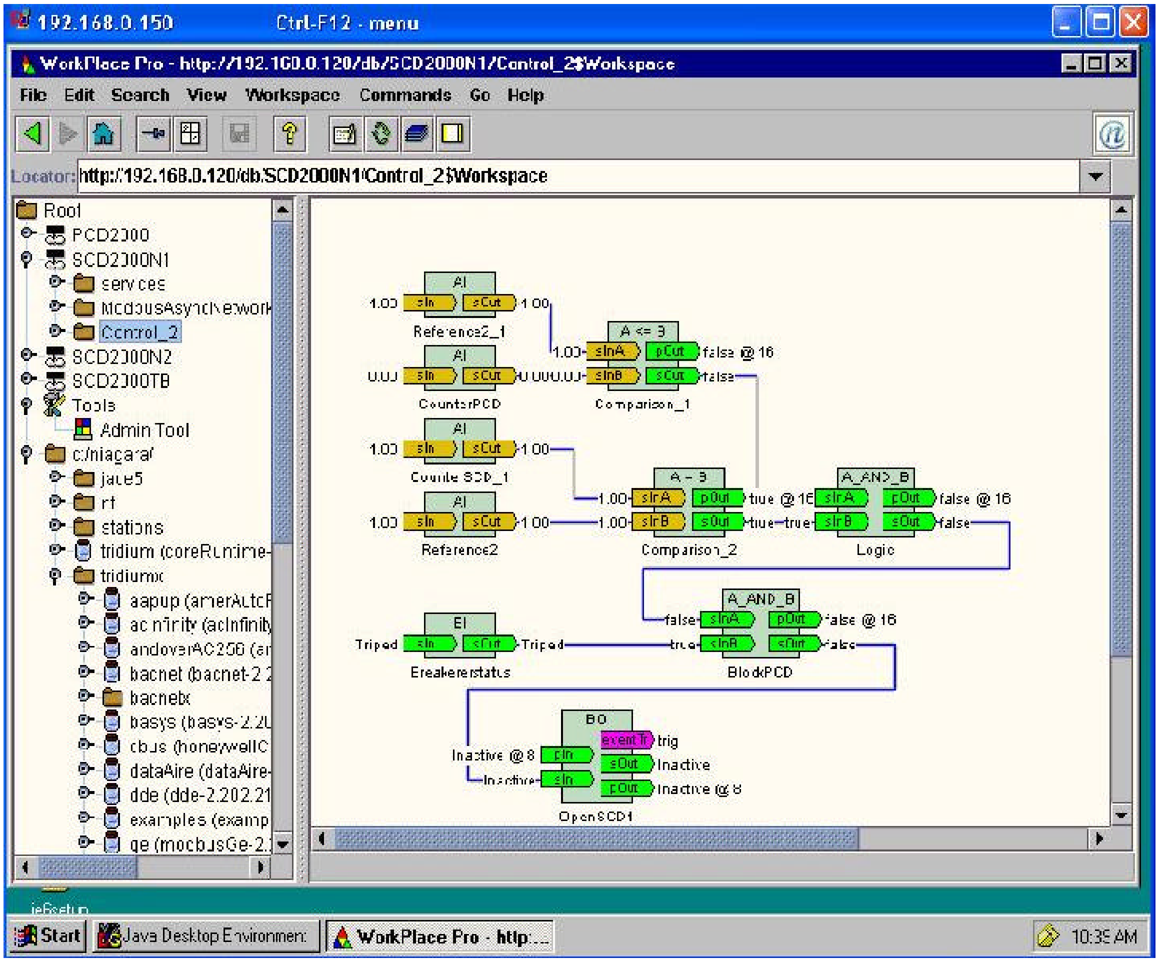


Figure 5.4. Tridium Work Place Pro

5.4 *Operating philosophy*

As it was discussed in section 5.1, the distribution system model shown in Figure 5.1 is the framework to be used during the implementation of the Web-Based Peer-to-Peer Automation Distribution System. The ModBus configuration of the PCD2000 and SCD2000s includes a register (40819) which provided an event counter during fault occurrence. For PCD2000s units the 40819 register starts at 0. It is incremented by one after every reclosing operation of the recloser. In the case of SCD2000 units the 40819 register counts the reclosing operation in a slightly different manner. It starts in 1 and increases every time overcurrent is detected. The 40819 counter registers provide key information for fault location tasks. Comparing the event counter of successive PCD/SCD2000, it is possible to determine the location of the fault without having to wait for several reclosing operations.

The operating philosophy of the system is as follows:

The recloser is the only device capable of opening short circuit currents. Sectionalizers that see the fault ahead should be coordinated in such a way that only the device closest to the fault should operate after the first unsuccessful reclosing operation and while the recloser is open. Furthermore, it has to send an open/lock command to the device located immediate down stream of it. Every device that remains closed down-stream of the faulted line must switch to alternating settings in order to assure coordination with the protection devices of the backup feeder. Once the fault was completely clear (both edge devices open) both the recloser and the tie breaker close reenergizing the un-faulted load. It is important to remark that although there is enough data to initiate the process before the first reclosing operation, the system always allows one reclosing operation in order to avoid operating for a non-permanent fault.

The communication system works as follow:

Devices are constantly posting in the network their event counter (40819) and status registers (open/close). Furthermore, they are constantly reading from the network event counter and status of all devices in the power distribution network. Having this information enables them to evaluate the system condition. When a fault occurs anywhere in the distribution system, the recloser starts its sequence of operations. Thus, event counter registers increase with every reclosing operation only in devices that see the fault current. The fault location is accomplished by comparing 40819 register of successive devices. If a device sees the current but its down stream fellow does not, the fault is between them. Once the fault was located, the closest device masters the reconfiguration of the network. It generates and sends open/close/lock commands to other devices according to the operating philosophy described above.

In order to better understand what is stated in the previous paragraphs, let’s consider Figure 5.5. The logic schemes for permanent faults in F1, F2 and F3 are shown in Table 5.1, Table 5.2 and Table 5.3 respectively.

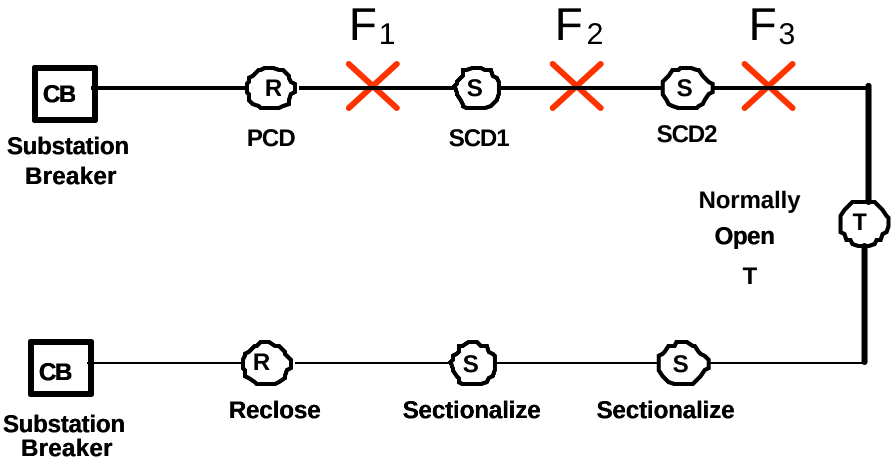


Figure 5.5 Distribution System Model

Table 5.1. **Logic Scheme for a Permanent Fault at F1**

Time	40819	Status	Response
0	PCD=0 SCD1=1 SCD2=1	PCD=C SCD1=C SCD2=C T=O	
0+	PCD=0 SCD1=1 SCD2=1	PCD=O SCD1=C SCD2=C T=O	PCD opens and momentarily clears the fault current.
0.5 Sec	PCD=1 SCD1=1 SCD2=1	PCD=C SCD1=C SCD2=C T=O	PCD recloses. First reclosing operation. Event counter register increase only in PCD. Neither SCD1 nor SCD2 senses current fault. Therefore they do not increase their event counter and remain close.
	PCD=1 SCD1=1 SCD2=1	PCD=O SCD1=C SCD2=C T=O	PCD senses the fault and opens clearing the fault current momentarily. All registers remain unchanged.
	PCD=1 SCD1=1 SCD2=1	PCD=O SCD1=C SCD2=C T=O	SCD2 reads from the network SCD1-40819 register. Since SCD1-40819=1 and SCD2-40819 = 1 , the fault is not between SCD1 and SCD2. Therefore they do not have to take any action.
	PCD=1 SCD1=1 SCD2=1	PCD=O SCD1=C SCD2=C T=O	SCD1 reads from the network PCD-40819 register. Since PCD-40819=1 and SCD-40819 = 1 , the fault is between PCD and SCD.
	PCD=1 SCD1=1 SCD2=1	PCD=O/L SCD1=O SCD2=C T=O	SCD1 masters the system reconfiguration. SCD1 opens itself. It also sends a lockout command to PCD.
	PCD=1 SCD1=1 SCD2=1	PCD=O/L SCD1=O SCD2=C T=O	Tie breaker read from the network PCD counter, PCD status, SCD1 counter and SCD1 status. Since PCD-40819 = 1 and PCD status is locked and SCD1 status is open, Tie breaker send a changing settings command to SCD2.
	PCD=1 SCD1=1 SCD2=1	PCD=0/L SCD1=0 SCD2=C/AS T=O	SCD2 changes to alternating settings
	PCD=1 SCD1=1 SCD2=1	PCD=O/L SCD1=O SCD2=C/AS T=C	SCD2 reads from the network confirmation that T alternating settings have been set up. Thereafter, it close itself
10 Sec	PCD=1 SCD1=1 SCD2=1	PCD=O/L SCD1=O SCD2=C/AS T=C	Unfaulted load are fed by the backup source.

Table 5.2. **Logic Scheme for a Permanent Fault F2**

Time	40819	Status	Response
0	PCD=0 SCD1=1 SCD2=1	PCD=C SCD1=C SCD2=C T=O	
0+	PCD=0 SCD1=2 SCD2=1	PCD=O SCD1=C SCD2=C T=O	PCD opens and momentarily clears the fault current.
0.5 Sec	PCD=1 SCD1=3 SCD2=1	PCD=C SCD1=C SCD2=C T=O	PCD recloses. First reclosing operation. Event counter register increase in PCD and SCD1 because they see fault current. SCD2's event counter remains unchanged.
	PCD=1 SCD1=3 SCD2=1	PCD=O SCD1=C SCD2=C T=O	PCD senses the fault and opens clearing the fault current momentarily. All registers remain unchanged.
	PCD=1 SCD1=3 SCD2=1	PCD=O SCD1=C SCD2=C T=O	SCD1 reads from the network PCD-40819 register. Since PCD-40819=1 and SCD1-40819 = 3 , the fault is not between PCD and SCD. Therefore they do not have to take any action
	PCD=1 SCD1=3 SCD2=1	PCD=O SCD1=C SCD2=C T=O	SCD2 reads from the network SCD1-40819 register. Since SCD1-40819=3 and SCD2-40819 = 1 , the fault is between SCD1 and SCD2.
	PCD=1 SCD1=3 SCD2=1	PCD=O SCD1=O SCD2=O T=O	SCD2 masters the system reconfiguration. SCD2 opens itself. It also sends an opening command to SCD1.
	PCD=1 SCD1=3 SCD2=1	PCD=C SCD1=O SCD2=O T=O	PCD read from the network SCD1 counter, SCD1 status, SCD2 counter and SCD1 status. Since PCD-40819 = 1 and SCD1 status is open and SCD2 status is open, PCD closes itself .
	PCD=1 SCD1=3 SCD2=1	PCD=C SCD1=O SCD2=O T=C	Tie breaker read from the network PCD counter, PCD status, SCD1 counter and SCD1 status. Since PCD-40819 = 1 and SCD1 status is open and SCD2 status is open, Tie breaker (T) closes itself .
15 sec	PCD=1 SCD1=3 SCD2=1	PCD=C SCD1=O SCD2=O T=C	Unfaulted load are fed by the backup source.

Table 5.3. **Logic Scheme for a Permanent Fault at F3**

Time	40819	Status	Response
0	PCD=0 SCD1=1 SCD2=1	PCD=C SCD1=C SCD2=C T=O	
0+	PCD=0 SCD1=2 SCD2=2	PCD=O SCD1=C SCD2=C T=O	PCD opens and momentarily clears the fault current.
0.5 Sec	PCD=1 SCD1=3 SCD2=3	PCD=C SCD1=C SCD2=C T=O	PCD recloses. First reclosing operation. Event counter register increase in PCD, SCD 2 and SCD1 because they all see fault current.
	PCD=1 SCD1=3 SCD2=3	PCD=O SCD1=C SCD2=C T=O	PCD senses the fault and opens clearing the fault current momentarily. All registers remain unchanged.
	PCD=1 SCD1=3 SCD2=3	PCD=O SCD1=C SCD2=O T=O	SCD2 opens itself by internal settings.
	PCD=1 SCD1=3 SCD2=3	PCD=C SCD1=C SCD2=O T=O	PCD reads from the network SCD1-40819, SCD2-40819 and SCD2 status registers. Since SCD1-40819=3 and SCD2-40819 = 3 and SCD status is open, PCD close itself.

5.5 *Implementation*

The operating philosophy described in the previous section was implemented using the WorkPlace Pro Environment. The algorithm was implemented by combining Boolean operators and reading and writing Modbus commands. Some of the algorithms that were written on the JACE-501/502 units are shown below:

5.5.1 Recloser (PCD2000)

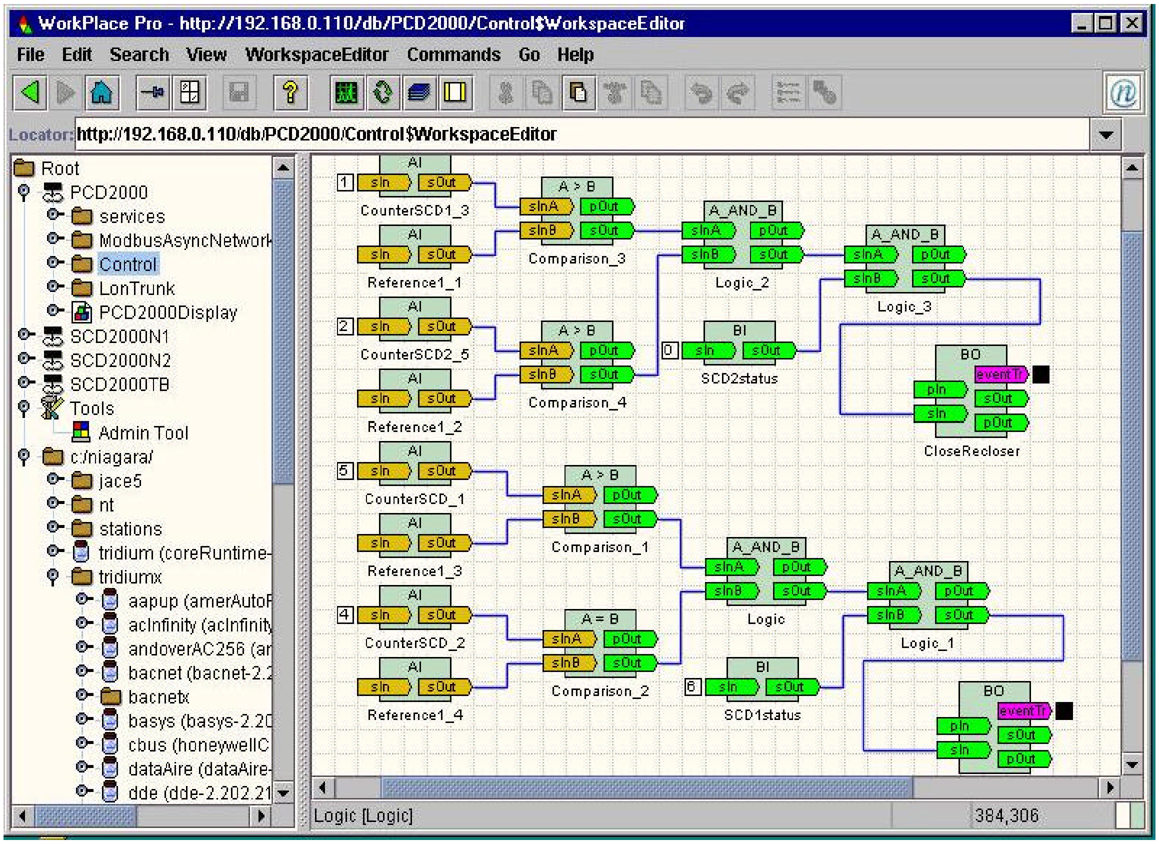


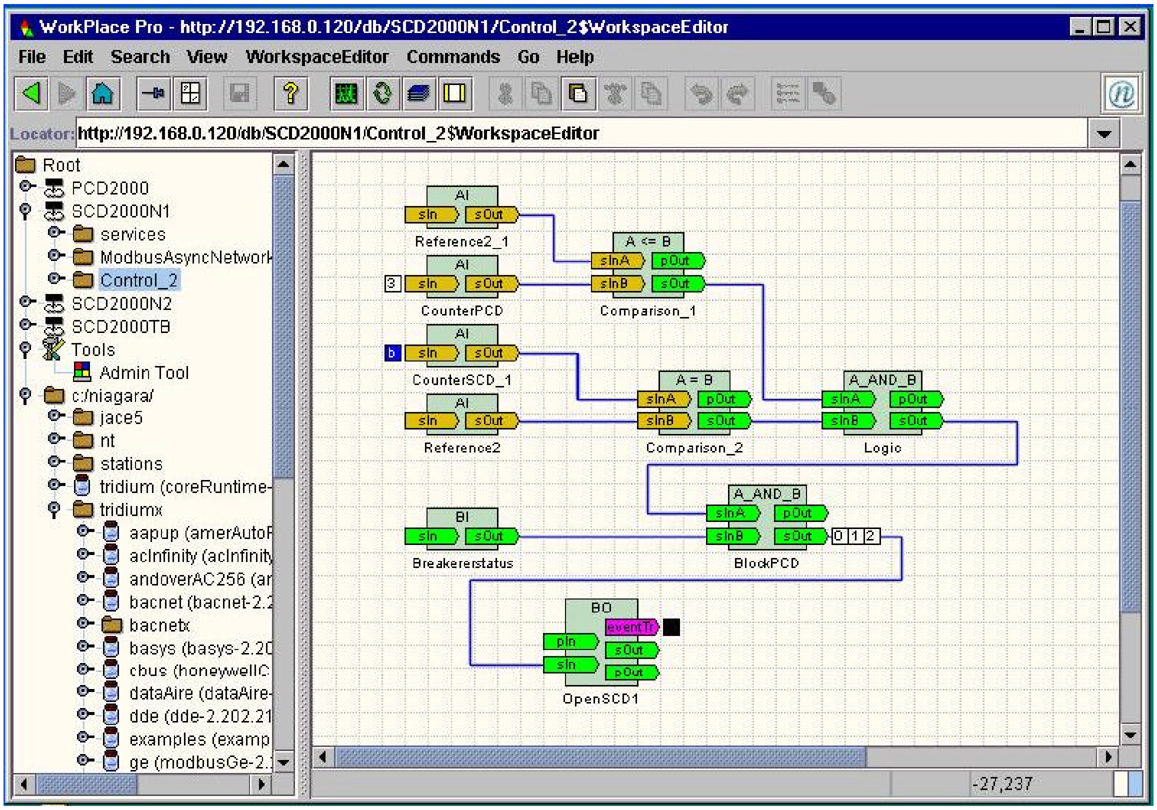
Figure 5.6. Recloser Algorithm

Logic for reclosing operation:

Fault at F3: If Counter SCD1 (Sectionalizer 1) is greater than 2 and Counter SCD2 (Sectionalizer 2) is greater than 2 and SCD2 status is open then close Recloser.

Fault at F2: If Counter SCD1 (Sectionalizer 1) is greater than 2 and Counter SCD2 (Sectionalizer 2) is equal to 1 and SCD2 status is open then close Recloser.

5.5.2 Sectionalizer 1 (SCD1)



Locator: http://192.168.0.120/db/SCD2000N1/Control_2$WorkspaceEditor

Figure 5.7. Sectionalizer 1 algorithm (SCD2000N1)

Logic for sectionalizer 1 (SCD1) operation:

Fault at F1: If Counter PCD (PCD2000) is equal or greater than 1 and Counter SCD1 (Sectionalizer 1-SCD2000N1) is equal to 1 and Recloser status is open then open SCD1 and also block PCD2000 (black link).

5.5.3 Sectionalizer 2 (SCD2)

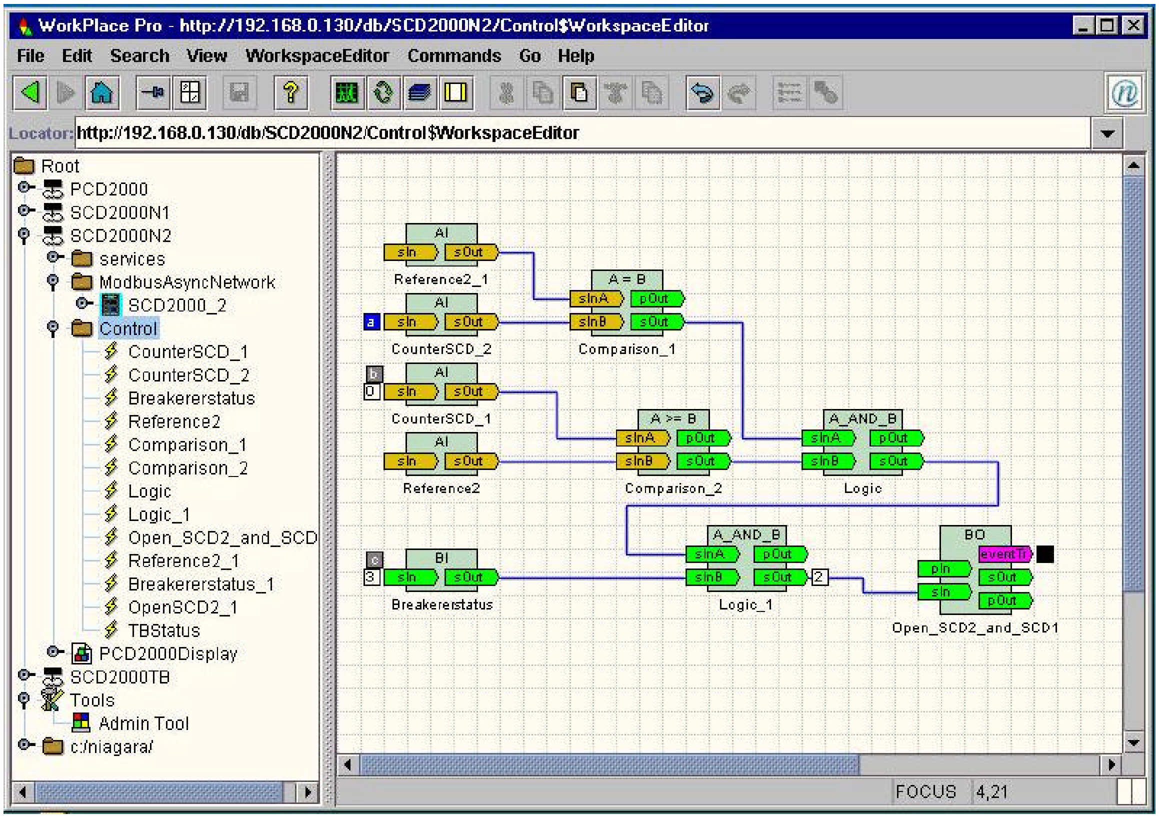


Figure 5.8. Sectionalizer 2 algorithm (SCD2000N2)

Logic operation for sectionalizer 2 (SCD2) operation:

Fault at F2:

If Counter Sectionalizer 2 (SCD2) is equal to 1 and Counter SCD1 (Sectionalizer 1) is equal or greater than 3 and Recloser status is open then open SCD2 and SCD1.

Note: For faults at F3, sectionalizer 2 (SCD2) automatically opens after the first unsuccessful reclosing operation. It is in accordance to the traditional protection scheme described in section 3.2.

5.5.4 Tie Breaker (T)

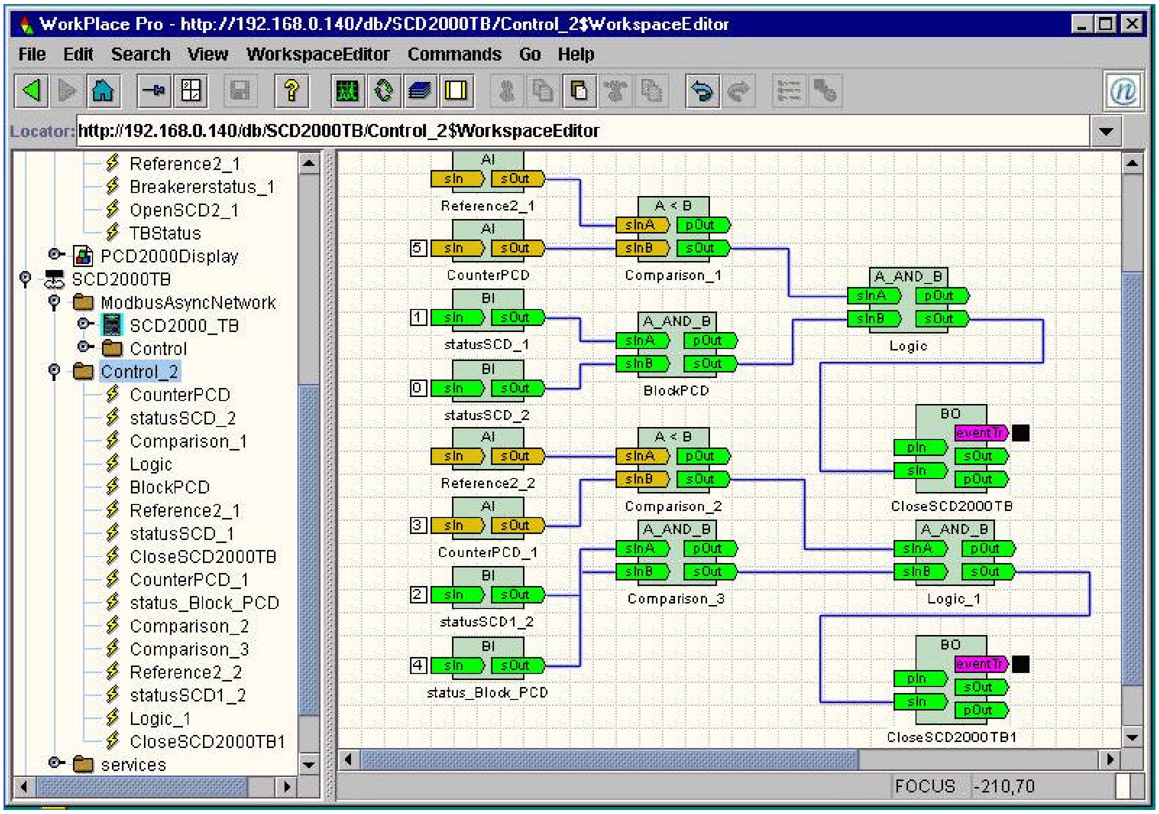


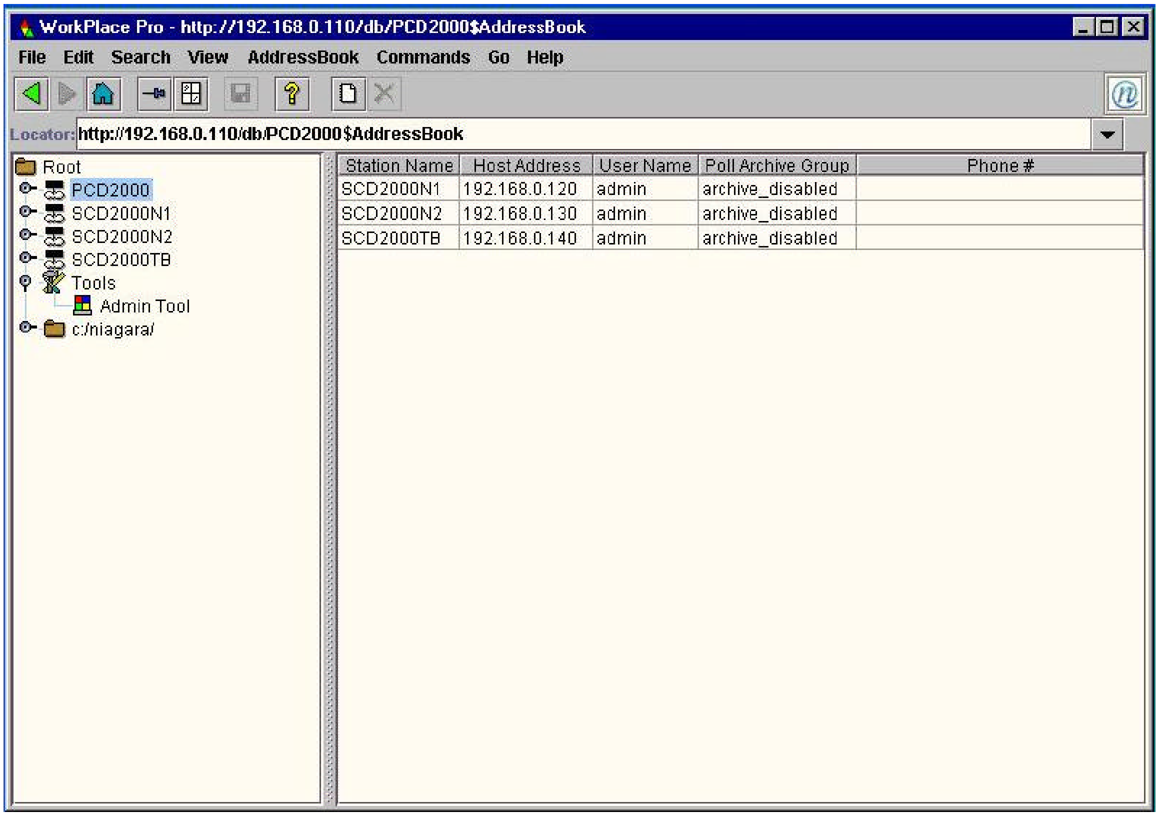
Figure 5.9. Tie Breaker algorithm (SCD2000TB)

Logic operation for tie breaker operation:

Fault at F2: If Counter PCD (Recloser) is greater than 0 and Status SCD1 is open and Status SCD2 is open then close SCDTB (Tie breaker).

Fault at F1: If Counter PCD (Recloser) is greater than 0 and PCD is blocked and Status SCD1 is open then change SCD2 to Alt. Setting and close SCDTB (Tie breaker).

5.5.5 General: Address books

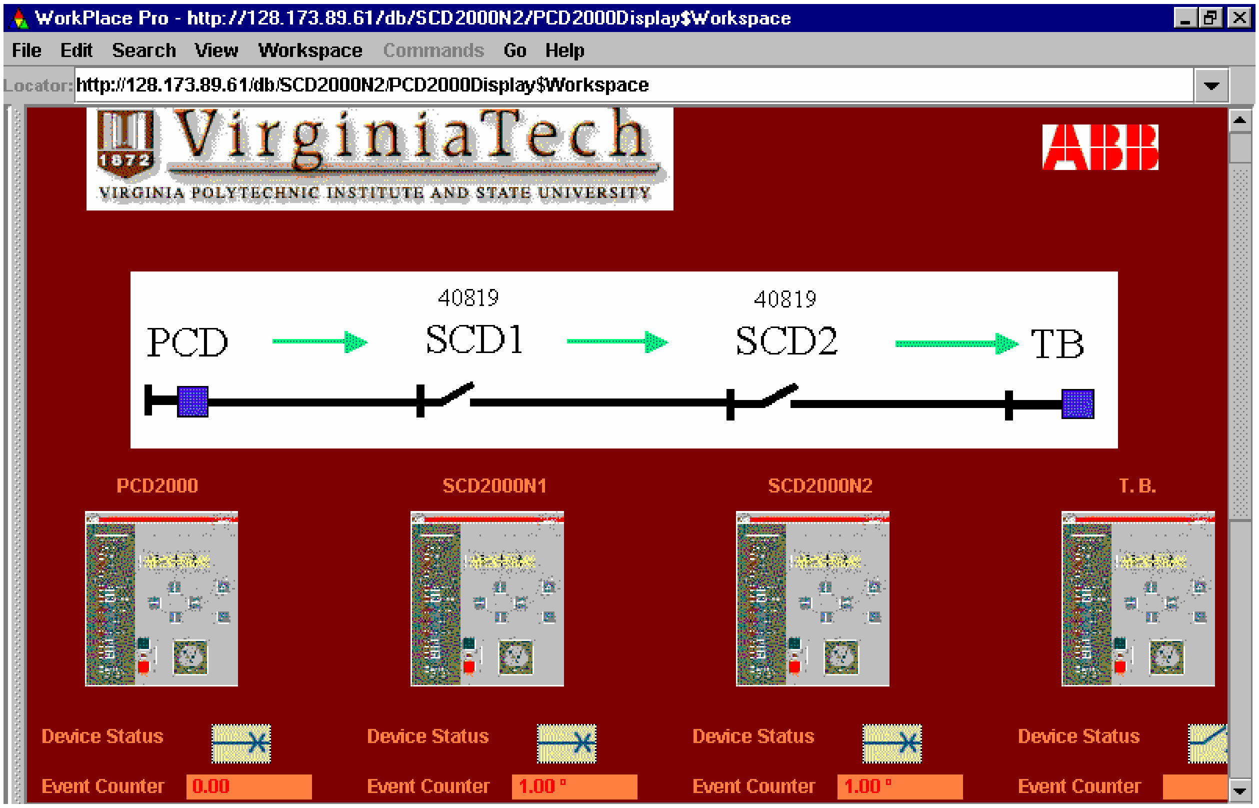


Station Name	Host Address	User Name	Poll Archive Group	Phone #
SCD2000N1	192.168.0.120	admin	archive_disabled	
SCD2000N2	192.168.0.130	admin	archive_disabled	
SCD2000TB	192.168.0.140	admin	archive_disabled	

Figure 5.10. Tie Breaker algorithm (SCD2000TB)

The JACE-501/502 units only communicate with devices included in their AddressBook. Figure 5.10 shows the AddressBook for the JACE-501/502 unit associated to the Recloser Control Unit.

5.5.6 General: Web Capability


WorkPlace Pro - http://128.173.89.61/db/SCD2000N2/PCD2000Display$Workspace

Locator: http://128.173.89.61/db/SCD2000N2/PCD2000Display$Workspace

PCD2000 Event Counter 0.00

SCD2000N1 Event Counter 1.00 °

SCD2000N2 Event Counter 1.00 °

Figure 5.11. Webpage Capability

WorkPlace Pro allows the configuration of webpages where real-time information of the distribution system can be displayed. Figure 5.11 is an example of what can be done using this feature. The above webpage gathers and displays real time field data such as Recloser and sectionalizer’s status and counters. It can also send open and close command to the devices. A security password and a valid JACE-5 license are required to access this webpage using standard internet browsers.

Chapter 6: Results

After successfully implementing the Internet Based Peer-to-Peer Comunication Reclosing-Sectionalizer scheme described in the above section several test were performed. Table 6.1 summarizes the obtained results. It shows a comparison in terms of the number of reclosing operations, unfaulted load losses, and recovery time for several contingences between the traditional protection system and Peer-to-Peer Communication-Based protection system applied to distribution networks.

Table 6.1: Comparison of the Traditional Protection Scheme and the Peer-to-Peer Communication Based Protection System.

Traditional Protection System			
Fault Location	Reclosing Operations	Unfaulted Losses	Recovery Time
F1	3	100%	N/A
F2	2	50%	180 Sec
F3	1	0%	45 Sec
Peer-Peer Communication Based Protection System			
Fault Location	Reclosing Operations	Unfaulted Losses	Recovery Time
F1	1	0%	10 Sec
F2	1	0%	10 Sec
F3	1	0%	10 Sec

According to Table 6.1, adding peer-to-peer communication to a traditional distribution protection system significantly enhances its performance. Assessing quality of service by means of measuring the percentage of undesired load losses, peer-to-peer communication based protection gets the highest score. In other words, for any contingence that may happen in the system no unfaulted load is lost. Indeed, only load connected to the faulted section is permanently shut down.

The results show that the Peer-Peer Communication Based Protection System performs fault location, fault isolation and system restoration functions in an average time of 10 Sec. This operating time heavily depends on the load and availability of the Intranet or Internet network. However, it is important to remark that the system is intended to operate within the dead time between the first and the second reclosing operations which is 15 sec for this particular application.

Another important enhancement accomplished with the implementation of the Peer-to-Peer Communication based Distribution Protection system is the reduction of the number of reclosing operation required to clear the fault. While the traditional protection system might require up to 3 reclosing operation before clearing the fault, the Peer-to-Peer protection system isolate the fault and restore power to unfaulted loads after the first reclosing operation regardless of its location in the distribution. It significantly reduces the stress under the distribution system is put on during successive unsuccessful reclosing operations.

A “Not Available Communication test” was also performed. As it was specified in section 5.4, when the communication fails, the system operates according to the traditional bang-bang recloser-sectionalizer distribution protection system, which in fact is always running in parallel to the Peer-to-Peer Communication Based Protection System.

Chapter 7: Conclusions

The Internet based Peer-to-Peer Communication Power Distribution Loop Control System was successfully implemented and tested. The traditional distribution protection system (recloser, sectionalizers) was configured to automatically isolate faulted circuits as well as to re-energize unfaulted loads after one reclosing operation. Internet based Peer-to-Peer communication allowed fast and reliable exchange of information between microprocessor based protection/control devices located at different points of the distribution feeder. According to the results, adding peer-to-peer communication to a traditional distribution protection system significantly enhances its general performance eliminating undesired losses of unfaulted load. Additionally, it reduces outage duration as well as thermal and mechanical stress due to successive re-energizations under faults condition.

Chapter 8: Future Work

Although the peer-to-peer communication based protective system was implemented and tested for a radial overhead distribution system, it is only one of many possible applications of an adaptive protection systems. Among these applications are:

- Underground Distribution System
- Power quality
- Remote supervision

As we have shown in this work, the Peer-to-Peer communication based protection distribution system is the result of bringing all together the latest advances in computer, communication and protection. Thus, a significant improvement in distribution system reliability has been achieved by blending all these new concepts in one specific application.

Underground systems may be the closest application for the concepts stated in this work. Overhead and underground operating philosophies differ in the number of reclosing operations they allow. As was described in this document, for overhead distribution system several reclosing operations over fault are allowed. However, reclosing operations in underground system are not permitted. It is because the potential damage that can be caused to the cables by the fault current flowing through them for long and successive period of time. Thus, Peer-to-Peer underground applications require location and isolation of the fault as well as system restoration after the main breaker has permanently cleared the fault. Having in mind this requirement and the concept stated by this research work, it can be possible to develop a Peer-to-Peer Loop Control Application for Underground Distribution Systems.

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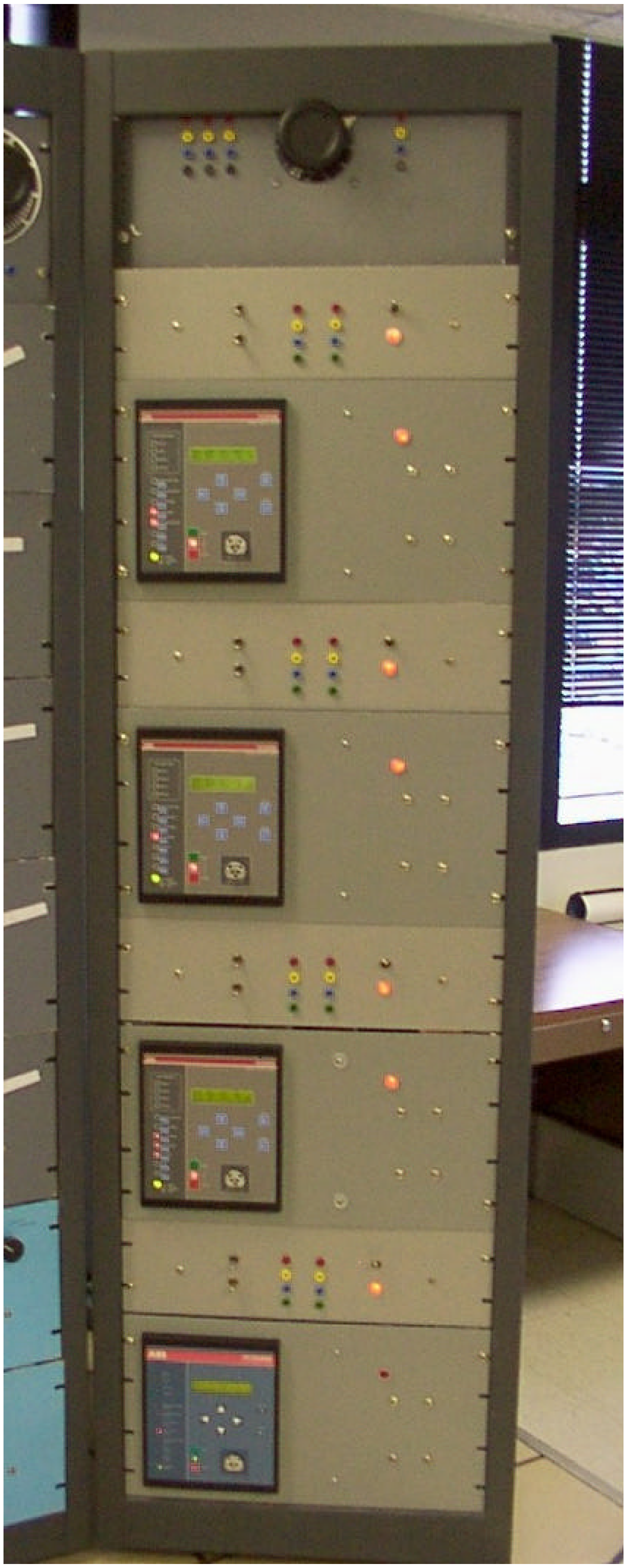
APPENDIX A:

Distribution feeder analog simulator

Distribution Feeder Analog Simulator



VITA

Juancarlo Depablos was born in Caracas, Venezuela on October 25, 1970. He received his Electrical Engineer Degree from the Simon Bolivar University at Caracas Venezuela in February 1992. He worked as Project Engineer for 10 years before pursuing his Master of Science Degree in Electrical Engineering (with emphasis on Power Systems Engineering) at the Virginia Polytechnic and State University starting in August of 2001.